SIGNAL MIXING IN FERRITES ON MICROWAVES

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In this paper the main formulae are derived for the mixing of microwaves in ferrites, and the results of experiments are described, which were carried out to check the theory.

Let us examine the case of a spheroid magnetized along the z-axis, which is the axis of symmetry. If the ferrite is subjected to high-frequency oscillations of frequencies ω_1, and ω_2, which are close to each other, the difference frequency component formed from the Landau - Lifshits equation is as follows:

$$\left|\frac{dM_z}{dt}\right| = \frac{\sqrt{P_1 P_2} \cdot (\omega_1 - \omega_2)}{\mu_0 V \Delta H \sqrt{\omega_1 \omega_2}} \tag{1}$$

where P_1 and P_2 are the powers absorbed in the ferrite sample at the frequencies ω_1 and ω_2;

V is the volume of the sample;

$2\Delta H$ is the width of the resonance curve.

If the difference frequency power is drawn off by a coil wound on the ferrite sample, which is connected in the resonant circuit, the voltage amplitude in the circuit is as follows:

$$U = QnS\left|\frac{dB_z}{dt}\right| = \frac{Q\sqrt{P_1 P_2}}{\Delta H} \frac{\omega_1 - \omega_2}{\sqrt{\omega_1 \omega_2}} \cdot \frac{nS}{V}(1 - N_z) \tag{2}$$

Here Q is the quality factor of the circuit (at the difference frequency);

n is number of turns of the coil on the ferrite;

All quantities in this formula can be determined experimentally.

The test set up which was used allowed us to measure the power absorbed by the ferrite at the frequencies ω_1 and ω_2, and also the voltage at a difference frequency equal to 30 mc.

The ferrite sample is installed in a rectangular waveguide at a distance of one half a wave length from the short-circuiting plug, that is, where the magnetic field bunches.

The main purpose of the experiment was to compare the experimental values for the difference frequency with the theoretical ones computed from formula (2). We used spherical samples, on which two turns of wire (of 0.1 mm dia.) were wound.

The ends of the wire were connected to a circuit tuned to the difference frequency, which had a quality factor Q equal to 15.

The plane of the turns was perpendicular to the direction of the dc magnetic field (fig. 1), while their position with respect to the dc field could be varied by turning dielectric rod, on which the ferrite was attached.

The measurement results and also the calculated values of the difference frequency signal for a manganese mono crystal and yttrium garnets are given in table I. The quantity δ in the table gives the discrepancy between measured and calculated values. These values compare well enough for monocrystals of different diameters since the value of δ lies within the limits of measurement accuracy.

Table 2 contains similar results for two types of polycrystalline ferrites. We see that the discrepancy between the experimental and calculated values for the signals amounts to 20 decibels on the average for the type HM-2 ferrite and 30 decibels for the type M-50 ferrite. This discrepancy cannot be attributed to measurement errors however.

We believe this discrepancy between theory and experiment may be explained if we consider the polycrystalline ferrite as a first approximation to be a system of monocrystals coupled to each other, where formula (I) is applicable to each of the latter.

In this case the quantity ΔH in formula (I) will correspond to the width of the absorption curve for a single monocrystal in the polycrystalline sample.

Since the crystallographic axes of the individual monocrystals are directed randomly in the sample, the dc magnetic field applied to the sample will not be the resonant field for all monocrystals. This is one of the main factors determining the large width of the absorption line for polycrystalline ferrites.

The width of the absorption line for a polycrystalline sample is determined by other factors, also (e.g. stresses, internal nonuniformities in the magnetic moment, etc.) None the less, it will not be narrower than the difference between the resonance fields for the direction in which it is easy and hard to magnetize the sample.

Thus, formula (I) should be applied to each of the monocrys-

tals forming the polycrystal, and then all the signals should be summed up.

In doing so, the quantity ΔH may be taken as a first approximation to be constant. Then, the summing process amounts to determining the powers absorbed by the sample as a whole. This quantity is just what was determined in the experiments (see table 2).

Thus, we come to the conclusion, that for polycrystalline samples we should use in formula/ (I) /and consequently in formula (2) /the unknown quantity ΔH, which corresponds to the width of the resonance curve for a single monocrystal.

If this reasoning is true, the value of ΔH may be determined from measurements of the difference frequency signal.

Using formula (2) and data of table 2 we obtain: for the type HM-2 ferrite $2\Delta H = 32$ oersteds and for the type M-50 ferrite $2\Delta H = 14.5$ oersteds. It is entirely possible that such a method of determining ΔH for different monocrystals may be used in investigating ferrites.

Another series of experiments were carried out to investigate certain particularities of mixing phenomena in ferrites. Only some of the results obtained are given below.

Curves for the signal and absorption in ferrite are given in fig. 2 as a function of the dc magnetizing field for different diameters of the ferrite rods. The latter were placed along the axis of a square waveguide, and were magnetized by a longitudinal field (see the drawing).

As we see from the drawing, the maximums for the ferrite

absorption curves shift towards stronger magnetic fields as the diameter of the rod is increased (its length is constant and equal to 10 mm). This is connected with changes in the demagnetizing factors. Here, the maximum of the signal coincides with the corresponding maximums for absorption in ferrite. This confirms that formula (2) is correct. It follows from this formula that the dc field only influences the magnitude of the signal through the power absorbed in the ferrite (this is true for polycrystalline as well as for monocrystalline ferrites).

As the rod diameter is increased above a certain value, the signal ceases to increase and then at a diameter of 2 mm it even begins to decrease. This is associated with the fact that a rod 2 mm in diameter already absorbs almost all of the power; further increase in the diameter only impairs the structure of the field in the ferrite, and results in wider absorption curves and, consequently, in wider signal curves.

A decrease in the ΔH of the material results in the appearance of additional peaks in the absorption and the signal. The peaks increase in number as ΔH decreases and the ferrite diameter increases. This can be clearly seen from fig. 3, which presents curves for the type HM-2 polycrystalline ferrite ($2\Delta H$ = 320 oersteds), and from fig. 4, which is for monocrystalline ferrite ($2\Delta H$ = 60 oersteds).

Similar phenomena are observed when ferrite spheres are placed in a resonator, which resonated at both frequencies.

Finally, let us examine the losses involved with one possible design of a ferrite mixer. It is connected in a balanced circuit as shown on fig. 5. A heterodyne is connected to the input channels of the short-slot hybrid junction and a signal is applied. Two short-circuited sections are connected to the output channels. They have type M-50 ferrite rods 3 mm in diameter and 10 mm long. The conversion loss amounted to 58 decibels for a heterodyne power of 50 milliwatts. In order to reduce this figure to 8 - 10 decibels (as in the crystal mixer), it is necessary to increase the heterodyne power by 48 to 50 decibels, that is, up to 3 - 5 kw. However, regeneration will appear even at much lower power levels. This will most likely strengthen the mixing effect and, consequently, will reduce the required heterodyne power.

In closing we should like to state that similar experiments were carried out at shorter and longer wave lengths, however, no new phenomena were discovered.

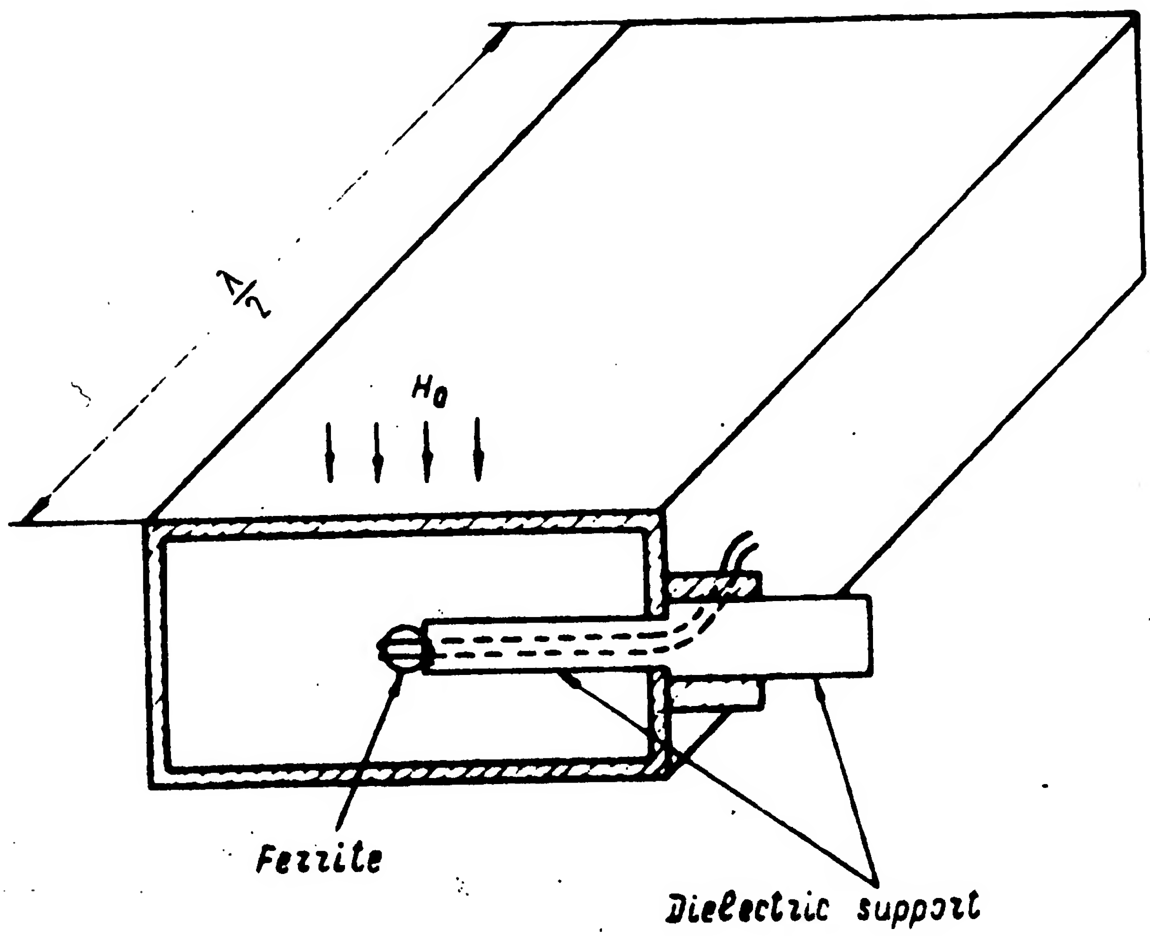


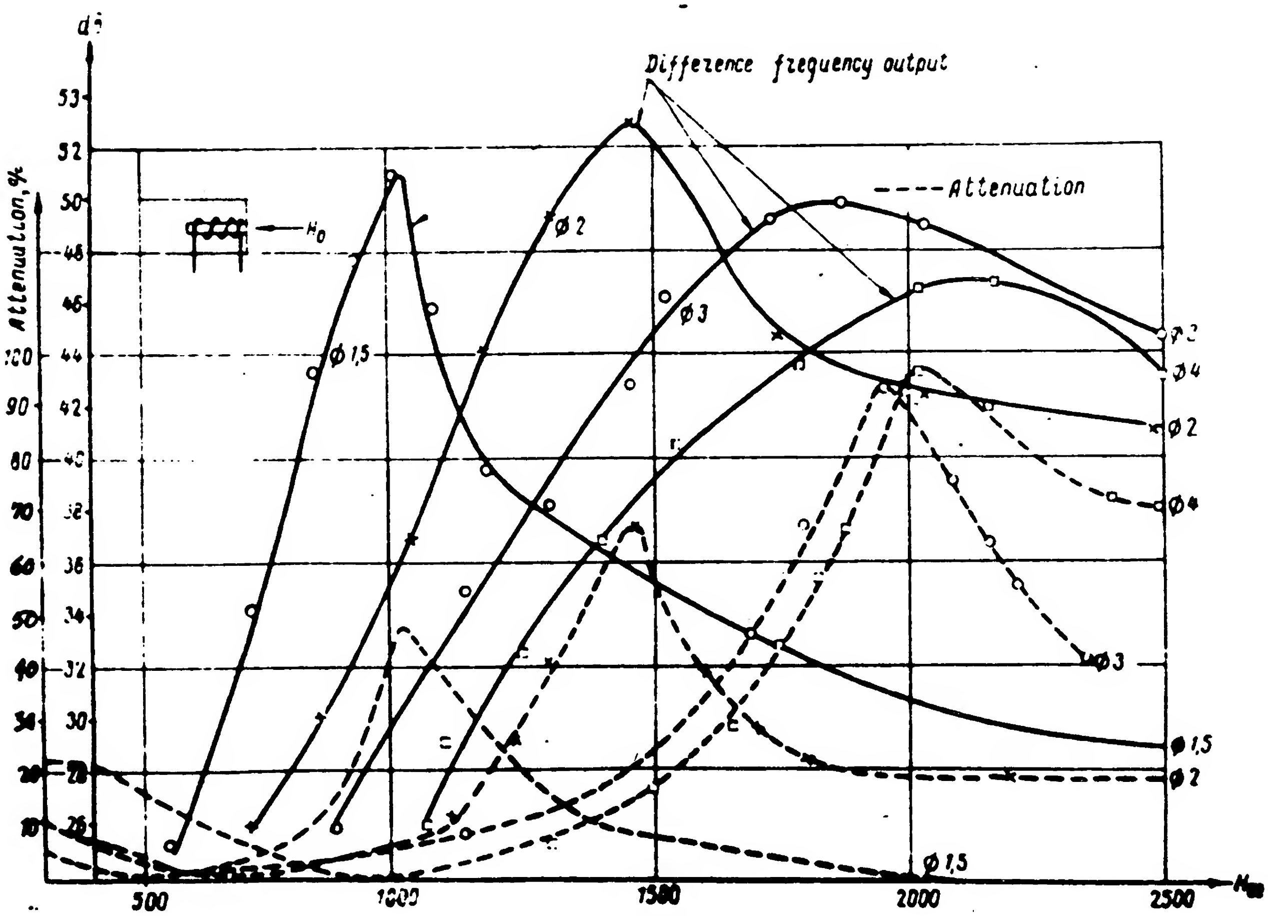
Fig. 1

Table 1

Ferrite	The diameter of spheres (mm)	2ΔH (oe)	$\frac{P_{abs}}{P_{in}}$ % ($H_0 = H_{res}$)	Difference frequency output		δ (dB)
				measured (dB)	calculated from (2) (dB)	
Single cristals of manganese ferrite	0,79	51oe	2,4	6,9	5,5	+1,4
	1,07	42oe	12,0	16,1	18,5	-2,4
	1,27	58oe	15,5	17,3	16,4	+0,9
	1,4	56oe	25,0	21,1	20	+1,1
	2,15	60oe	41,3	20,5	20,2	+0,3
Single cryst of yttrium iron garnet	0,5	7oe	1,5	10,3	16,3	-6
	0,85	12oe	3,8	23,8	20,6	+3,2
	1,28	26oe	14,5	30	25	+5

Table 2

Ferrite	The diameter of spheres (mm)	2ΔH (oe)	$\frac{P_{abs}}{P_{in}}$ % ($H_0 = H_{res}$)	Difference frequency output		δ (dB)
				measured (dB)	calculated from (2) (dB)	
HM-2 $4\pi M_s = 2800$	1,4	320oe	5,5	10,4	-7,7	+18,1
	1,73		8,0	13,3	-6,9	+20,2
	2,12		14,8	18	-3,2	+21,2
	2,5		20,0	19,8	-1,6	+21,4
	2,8		28,5	21	0	+21
M-30 $4\pi M_s = 4100$	1,38	460oe	3,8	21	-10	+31
	1,51		6,3	23,2	-6	+29,2
	1,65		7,8	25	-4,9	+29,9
	1,92		11,3	27,4	-2,6	+30
	2,16		14,0	29,1	-23	+31,4
	2,42		16,8	30,8	-1,8	+32,6
	2,76		22,5	32,5	0	+32,5
	3,02		31,3	33,5	1,9	+31,6



db
Attenuation, %
Difference frequency output
Attenuation
Ø 1,5
Ø 2
Ø 3
Ø 4
H₀
500
1000
1500
2000
2500

Fig 2

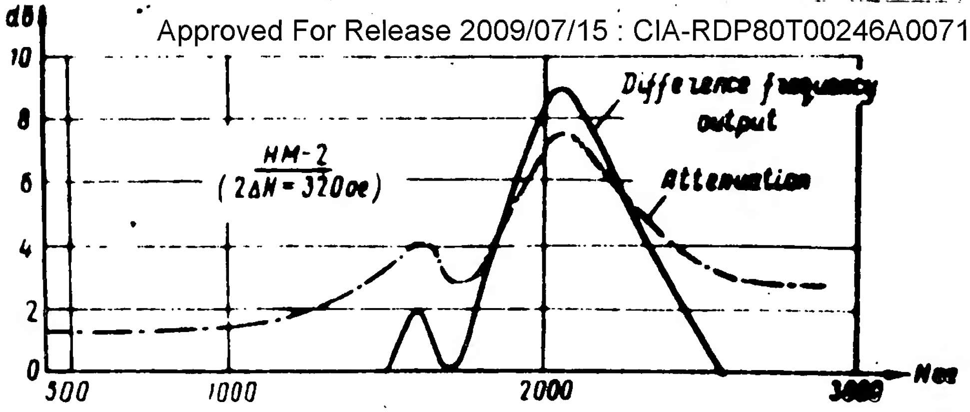


Fig 3

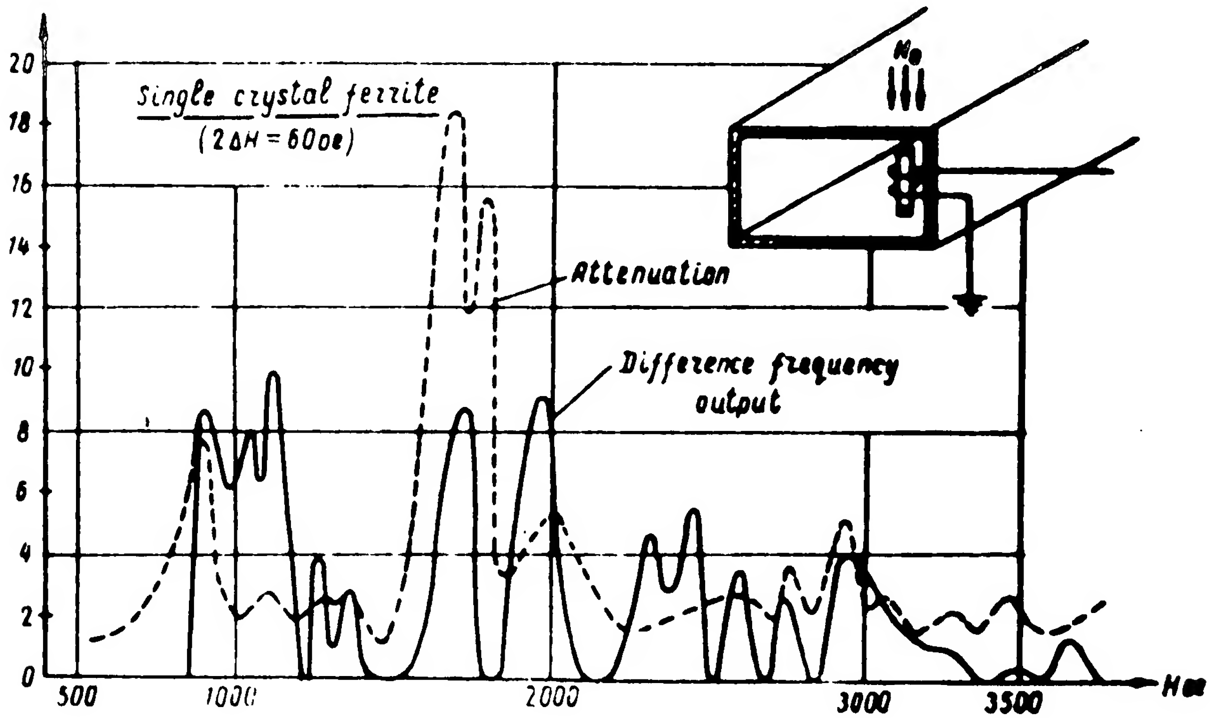


Fig 4

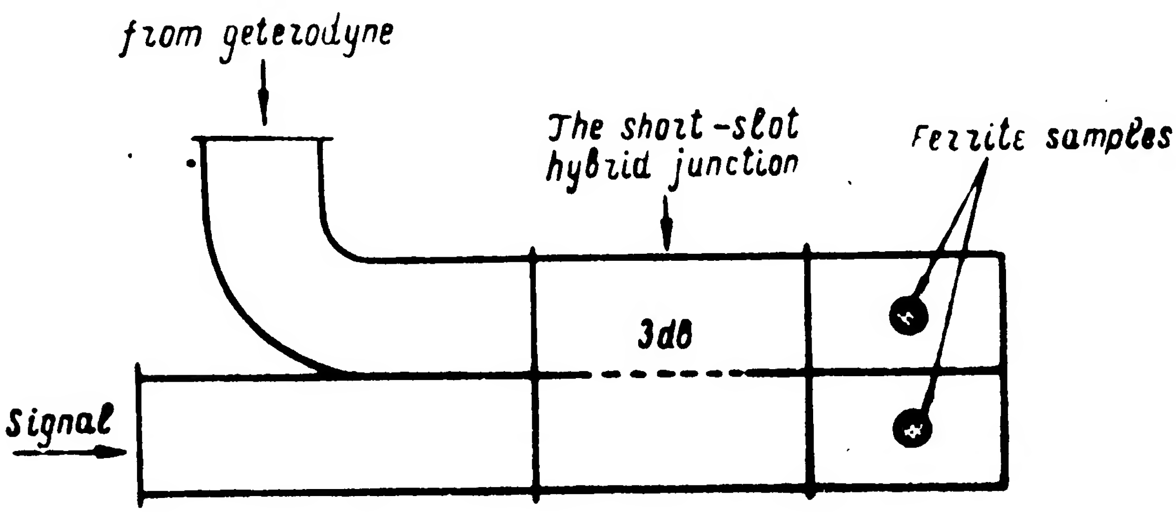


Fig. 5